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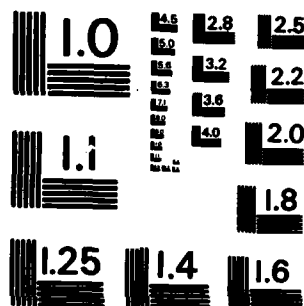
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) 1/f noise in unimplanted MOSFETs is also of the number fluctuations type. 1/f noise in JFETs is so small that it is almost unobservable. 1/f noise in buried channel MOSFETs is smaller than in diffused MOSFETs. Hot electron noise was observed in buried channel MOSFETs and in short channel JFETs. In the latter case it is masked by generation-combination noise due to partly ionized donors below 120°K. Low-frequency noise in GaAs current limiters is		

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one-dimensional diffusion noise governed by an activation energy that is voltage dependent. Modulation-doped GaAs FETs (HEMTs) have a sizeable amount of $1/f$ noise, probably of the number fluctuations type and thermal noise at higher frequencies. Short $n^+-n^-n^+$ GaAs diodes have a linear characteristic, show a small amount of $1/f$ noise and have thermal noise of the conductance at higher frequencies. The high-frequency behavior of short $n^+-n^-n^+$ GaAs diodes and of short n^+-n^- -grid- n^-n^+ solid state diodes was estimated; picosecond electronics seems feasible. Low frequency $1/f$ noise in HgCdTe changes to an $(A/f)\tan^{-1}(\omega\tau_1)$ spectrum after sputtering because the long surface time constants are sputtered off in the process.

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- A. List of papers published during the period March 1981 - Oct. 1982.
1. S. K. Kim, A. van der Ziel and S. T. Liu, Hot electron noise effects in buried channel MOSFETs, *Solid State Electronics*, 24, 425-428, May 1981.
2. S. K. Kim and A. van der Ziel, Hot electron noise and g-r noise in Short-channel JFETs, *Solid State Electronics*, 24, 429-434, May 1981.
3. A. van der Ziel, R. J. J. Zylstra and H. S. Park, Discrimination between $1/f$ noise models in junction field effect transistors and metal-oxide semiconductor field effect transistors, numerical results, *J. Appl. Physics*, 52, 4300-4304, June 1981.
4. C. H. Suh, A. van der Ziel and R. P. Jindal, $1/f$ noise in GaAs MESFETs, *Solid State Electronics*, 24, 717-718, August 1981.
5. A. van der Ziel, Thermal noise in the semiconductor regime of double-injection space-charge-limited solid-state diodes, *Physics*, 103B, 358-367, Feb. 1981.
6. Papers published at the Sixth International Conference on Noise in Physical Systems, April 6-10, 1981, Washington, D.C.:
 - a) A. van der Ziel, Thermal noise in the semiconductor regime of double injection diodes, N.B.S. Special Publication, 614, 88-92, 1981.
 - b) H. S. Park and A. van der Ziel, $1/f$ noise models in MOSFETs, N.B.S. Special Publication, 614, 226-229, 1981.
 - c) C. F. Hiatt, A. van der Ziel and R. J. J. Zylstra, Thermal interpretation of low $1/f$ noise in JFETs, N.B.S. Special Publication, 614, 234-235, 1981.
 - d) C. H. Suh, A. van der Ziel and R. P. Jindal, $1/f$ noise in GaAs MESFETs, N.B.S. Special Publication, 614, 236-239, 1981.
7. H. S. Park, A. van der Ziel and S. T. Liu, Comparison of two $1/f$ noise sources in MOSFETs, *Solid State Electronics*, 25, 213-217, March 1982.
8. H. S. Park and A. van der Ziel, Dependence on MOSFET noise parameters in n-channel MOSFETs, *Solid State Electronics*, 25, 313-315, April 1982.
9. A. Peczalski and A. van der Ziel, Flicker noise in Gunn diodes, *Solid State Electronics*, 25, 571-575, June 1982.
10. A. van der Ziel and G. Bosman, The effect of gate-voltage dependent mobility on thermal noise in MOSFETs, *Solid State Electronics*, 25, 525-527, June 1982.
11. A. van der Ziel and G. Bosman, Collision-dominated limit of near-thermal noise in short solid-state diodes, *Physica Status Solidi*, a, 73, K87-91, 1982.
12. A. van der Ziel and G. Bosman, Collision-free limit of near-thermal noise in short solid state diodes, *Physica Status Solidi*, a, 73, K93-96, 1982.

13. A. van der Ziel and K. Amneriadis, Microwave theory of ballistic GaAs solid state diodes and triodes, *Physica Status Solidi*, a, 73, 55-60, 1982.

14. A. Peczalski, A. van der Ziel and M. A. Hollis, Noise in short $n^+-n^-n^+$ GaAs diodes, *IEEE Trans., El. Div.*, ED-29, 1837-1839, Dec. 1982.

B. Papers to be published:

15. H. S. Park and A. van der Ziel, Noise measurements in ion-implanted MOSFETs, *Solid State Electronics*, was accepted long ago but has not yet appeared for unknown reasons.

16. A. van der Ziel, M. Shur, K. Lee, T. H. Chen and K. Amneriadis, Carrier distribution and low-field resistance in short $n^+-n^-n^+$ and $n^+-p^-n^+$ structures, *IEEE Trans. El. Dev*, ED-30, Feb. 1983.

17. K. H. Duh, A. van der Ziel and H. Morkoc, $1/f$ noise in modulation-doped field effect transistors, *IEEE Electron Device Letters*, EDL-4, 1983, in the press.

18. A. Peczalski and A. van der Ziel, Low-frequency noise in GaAs current limiters, *Solid State Electronics*, 26, 1983, in the press.

19. K. Zheng, K. H. Duh, and A. van der Ziel, Eliminating low-frequency $1/f$ noise in HgCdTe by sputtering, *Physica B*, 1983, in the press.

20. A. van der Ziel, R. J. J. Zystra, H. S. Park and S. T. Liu,
being submitted.

C. Theses.

Mr. A. Peczalski completed his Ph.D. thesis in August, 1982, and passed his final oral exam. The thesis title was "Low frequency noise in GaAs devices."

D. Summary of Research Findings

1. According to Bosman the mobility fluctuation $1/f$ noise in silicon decreases strongly with increasing field; on the other hand number fluctuation $1/f$ noise should not. This can be used to discriminate between number fluctuation $1/f$ noise and mobility fluctuation $1/f$ noise in MOSFETs, in that $S_I(f)$ versus drain voltage $1/d$ should monotonically increase with $1/f$ under saturation for the number model, whereas $S_I(f)$ versus V_d should show a maximum well before saturation in the mobility model (papers 3 and 7).

Experiments indicated that diffused MOSFETs showed number fluctuation $1/f$ noise whereas ion implanted MOSFETs seemed to show mobility fluctuation $1/f$ noise. Since this is difficult to understand we have developed a buried channel model for the ion implanted MOSFETs; it takes into account that a buried channel is developed near the drain and that this reduced the $1/f$ noise (see below). Hence the ionimplanted MOSFET also shows number fluctuations $1/f$ noise (paper 20).

2. Hot electron noise was observed in buried channel silicon MOSFETs and in short-channel silicon JFETs. In both cases the hot electron noise increases with decreasing temperature. Below 120°K the hot electron noise in JFETs is masked by generation-recombination noise due to partly ionized donors. Because of the short time constant involved the g-r noise is practically white; near 77°K the noise attains a maximum because the Fermi level crosses the donor level (papers 1 and 2).

3. $1/f$ noise in JFETs can be very small (Hooge's parameter $\alpha < 10^{-7}$) so that it is practically unobservable. The reason is that there is practically no oxide to speak of, so the number fluctuation $1/f$ noise is negligible. The small value of α may pose a dilemma for the mobility fluctuation $1/f$ noise

model (paper 6c; K. H. Duh, unpublished). $1/f$ noise in buried channel MOSFETs is smaller than in diffused MOSFETs. The reason is that in the diffused MOSFET the channel is a surface channel, so that the electrons can interact strongly with oxide traps. In a buried channel the channel is ion-implanted and the electrons have to climb a potential barrier to interact with the surface; as a consequence the interaction of the electrons with the oxide traps is much weaker and hence the $1/f$ noise is smaller (see also paper 20).

4. Low frequency noise in GaAs current limiters is of the one-dimensional ion diffusion type, governed by an activation energy that is voltage dependent because of the Poole-Frenkel effect. One dimensional ion diffusion gives a well-known spectrum that is $1/f^{1/2}$ at low frequencies and $1/f^{3/2}$ at higher frequencies; in our case the turn-over frequency is voltage and temperature dependent; both dependences can be explained with the help of the model.

5. Modulation-doped GaAs FETs (HEMTs) have a sizable amount of $1/f$ noise that varies as V^2 at low drain voltages, as expected for any theory of $1/f$ noise in FETs, and saturates at saturation near the drain. The $1/f$ noise is probably of the number fluctuation type, caused by interaction of the channel electrons with traps in the thin undoped GaAlAs layer that separates the channel from the n^+ GaAlAs layer at the surface (paper 17).

We are presently engaged in studying thermal noise in the device. The thermal noise theory of the device was developed under an NSF contract.

6. Short $n^+-n^- - n^+$ GaAs are operating in a nearly ballistic mode (paper 14). The characteristic is practically linear, as expected from the modified Fry-Langmuir theory of the device. The $1/f$ noise is very small for two reasons:

- a) There is practically no surface (the n^- region is only 4000\AA long and is bordered on both sides by n^+ regions), so there is no number fluctuation noise.

b) There are no collisions with the lattice, so there is practically mobility fluctuation noise.

The thermal noise corresponds to the thermal noise of the device conductance, as expected for a linear resistor (paper 14).

7. Short $n^+-n^-n^+$ GaAs diodes and n^+-n^- grid- n^-n^+ GaAs solid state diodes (PBTs) with n^- regions of a few thousand Angstroms thick allow picosecond electronics. The high-frequency behavior of these devices can be estimated by applying the h.f. vacuum tube theory as an approximation (papers 11-13).

8. Low frequency noise in untreated HgCdTe is of the $1/f$ type in the whole low-frequency range. When the surface is cleaned by mercury sputtering the spectrum changes to $(A/f)\tan^{-1}(\omega\tau_1)$ with τ_1 equal to about a few tenths of a multisecond. This can be explained by a time constant distribution

$$g(\tau) d\tau = A d\tau/\tau \quad (1)$$

for $\tau_0 < \tau < \tau_1$, where $\tau_0 \ll \tau_1$, whereas the true $1/f$ noise is explained by the same constant distribution for $\tau_0 < \tau < \tau_1'$, where τ_1' is of the order of many seconds. Apparently the sputtering removes most of the surface layer and hence the long time constants $\tau_1 < \tau < \tau_1'$ that give the low-frequency $1/f$ noise. This is the clearest evidence that the $1/f$ noise in HgCdTe is of the (surface) number fluctuation type caused by interaction of the electrons with traps in the surface oxide (paper 19).

9. In some GaAs MESFETs the $1/f$ noise is of the form

$$(A/f) \left[1 - \frac{2}{\pi} \tan^{-1}(\omega\tau_0) \right] \text{ for } \omega\tau_1' \gg 1$$

where τ_0 is of the order of 10^{-4} seconds and τ_1' is of the order of many seconds. This proves that the $1/f$ noise is due to a distribution of time constants (paper 6d).

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